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HELICOPTER ROTOR DOWNWASH EFFECTS

U. S. Dept. of Agriculture, Forest Service • San Dimas Equipment Development Center

DISCLAIMER

May, 1969

Study observations contained in this report should be of interest to air operations and line personnel engaged in forest fire suppression. Recommendations listed on page 11 are approved. Further tests will be conducted when availability of larger helicopters becomes more defined.

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Director of Fire Control

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ABSTRACT

Downwash and rotor wake from low-flying helicopters has caused problems on fires. A short test using a screen or wall of smoke permitted measurement of rotor wake from Bell 204B and 47G3-B1 helicopters.

Guidelines pertaining to best speeds and altitudes to avoid ground effects were developed. Surface winds away from the fire above 10 miles per hour rapidly diminish effects directly beneath the flight path. Helicopters having high disc-loading (short blades, heavy weight) create more rotor wake and downwash.

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HELICOPTER ROTOR DOWNWASH EFFECTS

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INTRODUCTION

Helicopters achieve their lifting capabilities by thrusting a large volume of air downward while in flight. They also create a "rotor wake" which can be useful to agricultural applicators when close to the ground, since the vortices provide excellent coverage of foliage. For the firefighter, however, this is a different story. He needs to understand and avoid possible downwash effects of low-flying aircraft of any type. Under some flight conditions helicopters can create the greatest effects.

Guidelines and rules of thumb regarding best speeds to avoid such effects have been used but were never based on other than experience and opinions. Even then, fires were still affected by downwash or, more accurately, "rotor wake." Most felt that as long as a hover condition or flight below translation was avoided, the hazard was averted. This short study is aimed at providing more reliable guidelines regarding rotor wake and downwash and how to avoid their effects.

A literature search revealed that many others have been concerned with various aspects of this same problem. The military services are attempting to solve visibility problems encountered when several aircraft operate simultaneously under dusty conditions. Dirt ingestion into engines, hazards (from debris) to people on the immediate ground area, and tactical security from visible dust clouds are problems facing military helicopter users in the field.

However, most research efforts undertaken to study these problems were not directed toward defining the subtle effects on ground fires, particularly when the helicopter is in forward flight. Also, theoretical calculations of rotor downwash apply only to the area immediately below the rotor disc. Further discussion of attempts to develop such calculations will be found under <u>Test Results</u>.

The Los Angeles County Fire Department provided Bell 204B and 47G3-B1 helicopters for the test program on May 7, 1968. The test site, El Mirage Dry Lake, California, proved to be ideal. The weather was clear and the wind calm on the morning of the test.

DESCRIPTION OF TESTS

In order to observe the subtle effects of rotor wake down to the ground, it was decided to utilize a smoke curtain or wall to provide visual indications of the air movement. Rather than attempt to theorize on fire behavior, air movement on the ground of any magnitude was considered an "effect."

A straight flight course was staked out on the dry lakebed and marked with flagged stakes and 8-foot checkered pylons for reference (figure 1).

A Hulcher camera, operated at ten frames per second, was located laterally to the line of flight to record height-velocity; and a motion picture camera recorded end-on effects of each flight.

Three separate piles of burning automobile tires provided a smokescreen. A theodolite device permitted a quick visual check of height for each flight or pass.

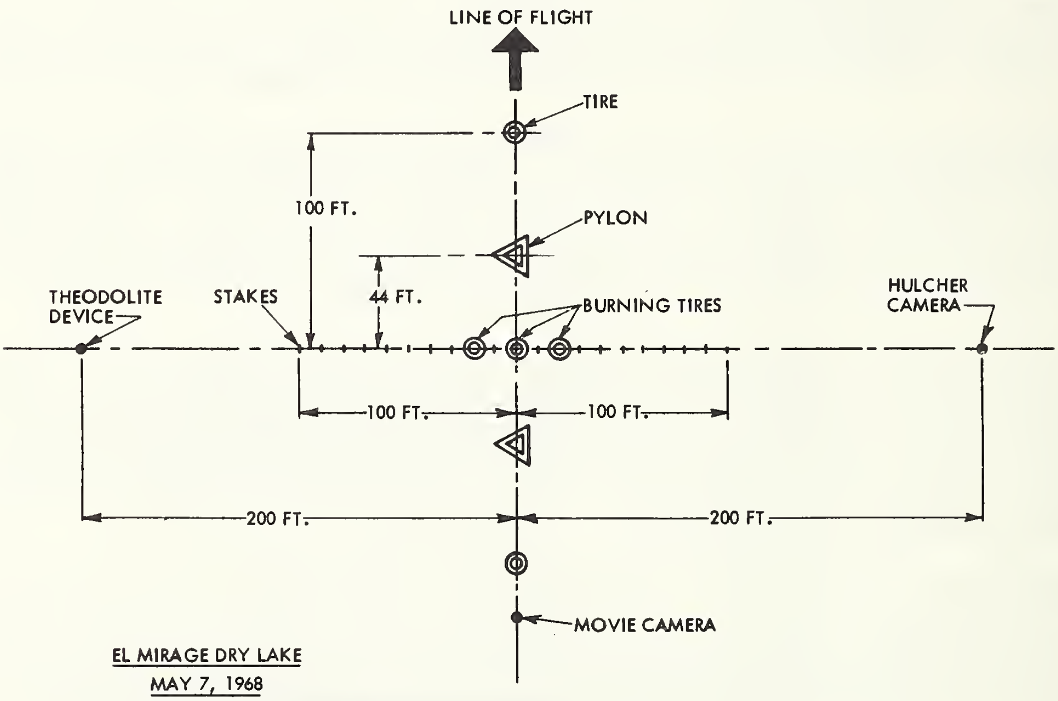

Figure 1. Test Layout

An attempt was made to record (by hand signals and a stopwatch) the time interval between pylons to estimate forward velocity. Reduction of actual velocities from the Hulcher film revealed this to be an inaccurate technique. An electric timing system should be used for future tests. Airspeed values from the aircraft instrument are too inaccurate for test work in the low-speed ranges.

The helicopters used for the test were as follows:

	Gross weight (lbs.) Start of test	End of test
Bell 204B, N7094S	6430	5480
Bell 47G3-B1, N1133W	2360	2270

Flights through the smokescreen were started at 50 feet for the 204B from 10 to 100 knots IAS in increments of 10 knots up to 50. (See data sheet for speeds.) The same speeds were flown at tapeline altitudes of 75 and 100 feet. At 100 feet, only speeds of 10 and 20 knots were flown. Hovers were performed at 100, 150, and 260 feet until the downwash became steady state.

Similar speeds were flown with the Model 47G3-B1 at heights of 50 and 75 feet. Hovers were performed at 100, 150, and 200 feet and a "quick-stop flare" at 60 feet above the smokescreen.

TEST RESULTS

There are many variables involved with analyzing the limited amount of data obtained from this "first test." At best, useful assumptions can be drawn as preliminary guidelines until further test work can be performed to obtain a complete range of data.

From an inspection of the results, both visual and recorded, the following areas should be considered as most important:

1. Vortices (or rotor wake) are created at all airspeeds. The magnitude and persistence were greater than expected by test personnel.
2. Rotor wake descends at a finite rate and is measurable with adequate instrumentation. Downwash in a hover also descends at a measurable rate until the column is established.
3. Lateral displacement of rotor wake and downwash occurs very rapidly with winds as light as 3-5 m.p.h. or even slight airmass drift.

Although these results appear to be general conclusions, they represent measurable areas which should be further examined. In reality, this short test program quickly developed these effects beyond the scope of instrumentation and time available.

The overall test data were obtained by hand recording and cross-checking with photographic results (table 1, appendix). As expected, the most difficult variable to control was airspeed. In the low range, the aircraft traveled faster than requested. An on-site electronic speedtrap is needed to obtain desired speed-range coverage.

Tapeline altitude was scaled directly from the Hulcher film, and vortex time to descend was later timed from motion picture coverage. In the future, a clock should be used in the foreground of the photographic scene.

In an attempt to predict amounts of induced or downward wake, theoretical values can be calculated with fair accuracy.

From known helicopter flight dynamics, the induced velocity in a hover at the rotor disc is related by the following equation:

$$V_h = \sqrt{\frac{W_T}{2A\rho B^2}}$$

where V_h = Induced velocity in a hover

W_T = Gross weight

A = Rotor disc area

ρ = Air density

B = Tip loss correction factor

$\frac{1}{B}$ = 1.13

From the above expression, it can be seen that the two main helicopter variables, $\frac{W_T}{A}$, or weight over disc area, becomes the common description of "disc loading." Thus, we can relate excessive effects from downwash in large, heavy helicopters with relatively short wide-chord blades. Longer blades would help alleviate this problem by lowering disc loading.

For the 47G3-B1, this velocity in a hover is about 35 m.p.h.; for the 204B, it is nearly 50 m.p.h. at 2,950 and 8,500 pounds, respectively.

When the helicopter moves into forward flight, the situation becomes a little more complicated in the wake, since the air is circulating in a multidirectional manner. However, the average vertical induced velocity at the rotor disc can be calculated from:

$$V_o = \frac{W_T}{2A\rho V} \quad \text{(for speeds above 30 m.p.h.)}$$

where V_o = Average vertical induced velocity at the rotor

W_T = Weight of aircraft

A = Rotor disc area

ρ = Air density

V = Forward speed

(The final downwash below the rotor disc contracts to 2 V_o.)

Bell Helicopter Company studies report the resultant average downward velocity (figure 2). Thus, at about 30 m.p.h., half the downwash occurs as at a steady-state hover condition.

The data from the tests were primarily of a visual nature regarding downwash and wake values. However, by noting the relative strength of ground level effects, figures 3 and 4 can be prepared. These trends follow the calculated values.

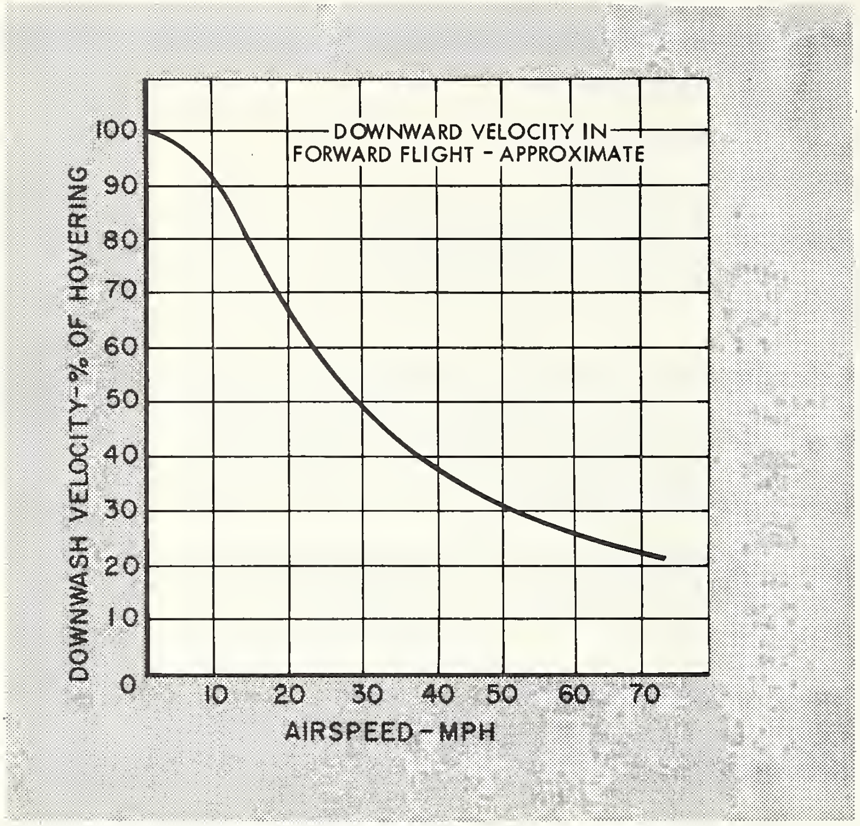

Figure 2

At first glance, this appears to limit "fly-bys" to very high speeds or heights; and this would be true under 0 wind conditions. However, most fire situations include winds, and any rotor wake or downwash moves with the wind mass. Distances traveled in the wind as a function of time can be determined (figure 5). For example, in 7 seconds a 10 m.p.h. wind travels close to 100 feet and a 20 m.p.h. wind, 200 feet.

Using a 10 m.p.h. prevailing wind away from the fire as a realistic minimum situation, we can then assume that any rotor wake or downwash taking longer than 7 seconds to reach the ground will have moved a safe lateral distance from the fire.

By reviewing the test data and plotting wake descents of 7 seconds or less, the areas are shifted (figure 6).

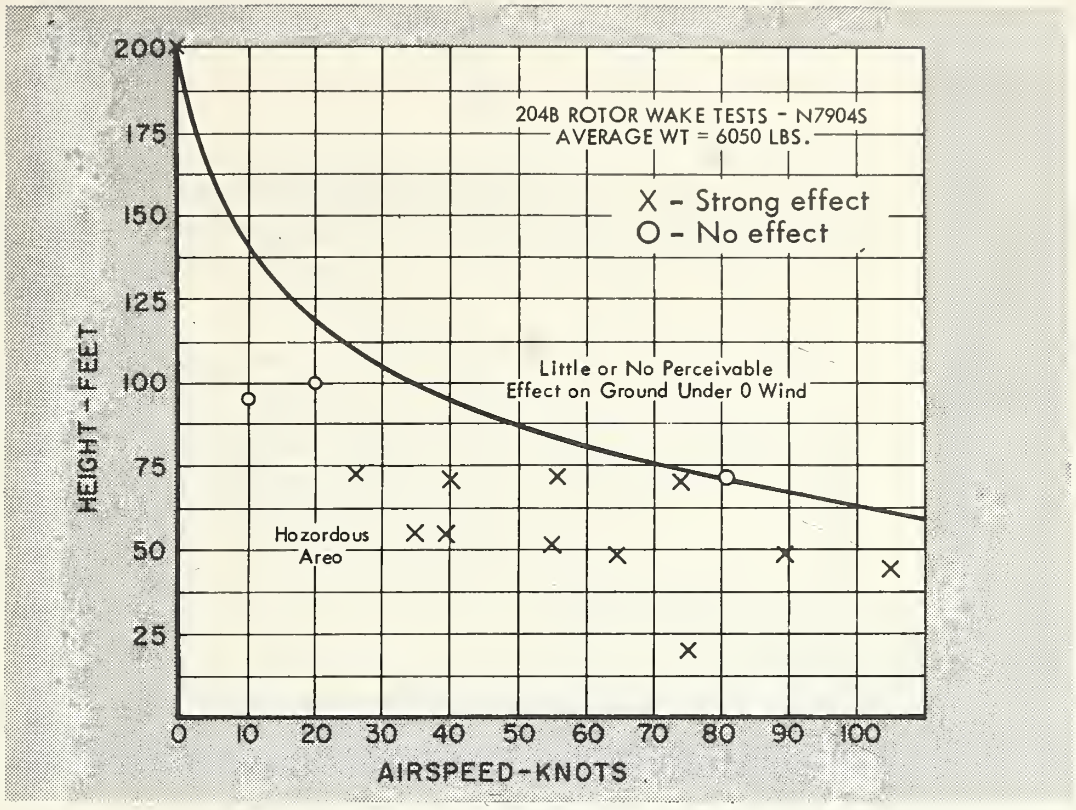

Figure 3

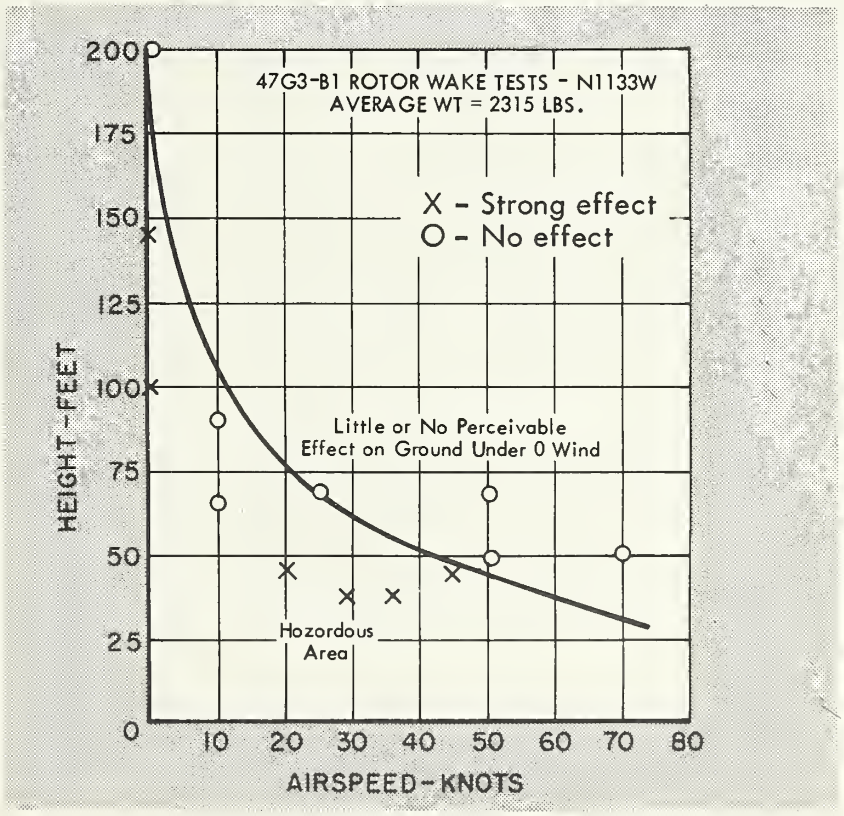

Figure 4

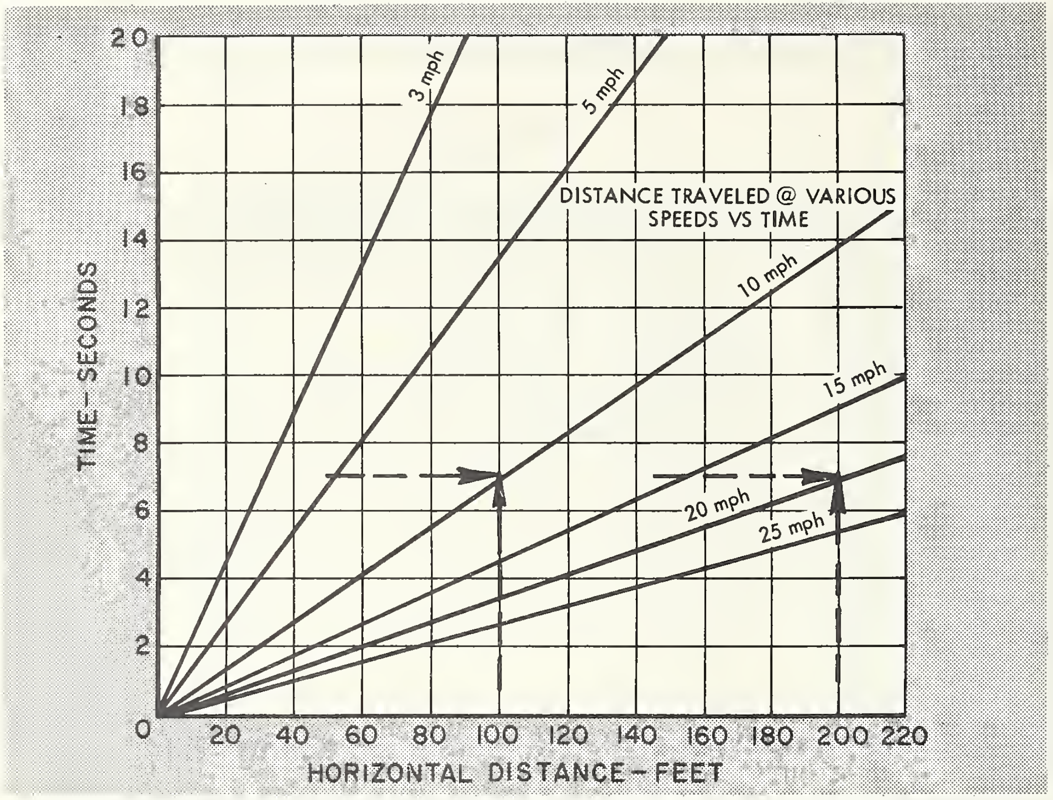

Figure 5

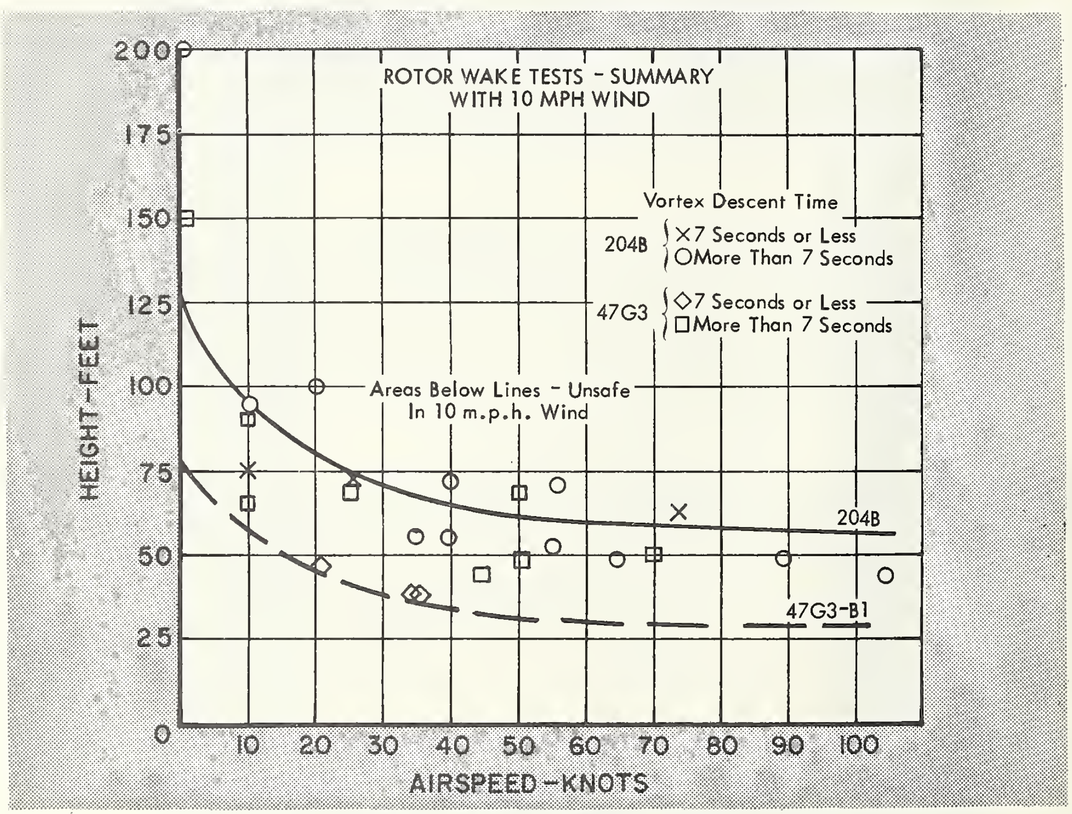

Figure 6

From examination of the results it is apparent that, under 10 m.p.h. wind conditions, the 204B should make "fly-bys" above 35-40 knots and above 50 feet. For the lighter Model 47 series, heights above 30 feet should be maintained at speeds above 35 knots.

For hovering situations with winds below 10 m.p.h., there is a potential effect below 100 feet for the 204B and 75 feet for the 47G3-B1. Even with winds above 10 m.p.h., caution should be exercised to make sure that the wind moves the downwash away from the fire. Also, when the column reaches the ground, some mushrooming or lateral movement in all directions can develop quickly and with noticeable strength.

Figure 7. Typical Rotor Wake Configuration

CONCLUSIONS

1. Rotor wake and downwash descends at a measurable rate until it reaches the ground or is dissipated. Its downward force decreases with increased airspeed but can create an effect on the ground up to speeds of 35 knots at low altitudes.

2. Wind motion will influence effects from rotor wake and downwash by carrying it laterally and dissipating its strength.

3. Hovering downwash is primarily a vertical column one-half rotor-diameter across and is potentially dangerous up to 300 feet when directed from the 204B. For the 47 series, 150 feet indicates strong ground wash effects.

4. Rotor wake at forward speeds is shed from the rotor disc as a sheet and rolls up at the edges as two counter-rotating vortices, which descend at a measurable rate.

RECOMMENDATIONS

1. For the 204B, drop passes or fly-bys should be made above 50 feet and at least 35 knots under average 10 m.p.h. wind conditions away from the fire. Under zero wind conditions, the height should be increased to 100 feet.

2. For Model 47 series helicopters, passes should be made above 30 feet and 35 knots under average 10 m.p.h. wind conditions away from the fire. Under zero or calm wind conditions, the height should be increased to 55 feet.

3. Hovering situations over fire should be avoided unless strong surface winds away from the fire are present.

4. Further tests should be conducted at maximum gross weights and with improved instrumentation to more fully define the limited data thus far obtained. As larger helicopters are presented, particularly with high disc-loading, rotor wake tests are recommended to at least establish the minimum safe height-velocity.

APPENDIX

TABLE I

204B FLIGHT DATA

Run No.	Reported IAS Kts.	Actual Grd.Spd. Kts.	Tapeline Alt.-Ft. First Pylon	Theodolite Ht.-Ft.	Estimated Vortex Time Seconds		Remarks
					To Reach Grd.	To Dissipate (1)	
2	10	35	53		9		
3	20	39	53		11		
4	30	55	51		16		
5	40	64	48		12	25	
6	50	89	48		14	25	
7	100	105	43		15	15	
8	90	73	62		7	10	
9	10			75	5	20	
10	20	27	72		7	24	
11	30	40	71		10	15	
12	50	56	71		15	10	
13	75	82	71				No visible effect
14	10			95	12	10	Light effect
15	20			100			No visible effect
16	Hover			75-100	5		Extreme effect
17	Hover			105-150	8		Extreme after est.
18	Hover			200-260	20		Severe after est.

Wt. Begin - 6430 lbs.
Wt. End - 5480 lbs.
Prevailing wind - 0.1 mph
O.A.T. - 40-48°F
H_I - 2770 ft.

Flight time - ∽ 40 min.

(1) Time vortex remained active after reaching the ground

47G3-B1 FLIGHT DATA

Run No.	Reported IAS Kts.	Actual Grd.Spd Kts.	Tapeline Alt.-Ft. First Pylon	Theodolite Ht.-Ft.	Estimated Vortex Time Seconds		Remarks
					To Reach Grd.	To Dissipate (1)	
19	10	21	47		6	15	
20	20	33	38		7	15	
21	30	36	38		5	15	
22	40	44	44		16	15	
23	50	51	48		20		Little effect
24	75	70	50				No visible effect
25	10			90			No visible effect
26	10			65			Slight effect
27	20	26	69		20		Slight effect
28	50	50	68				Slight effect
29	Hover			95-100	12		Extreme effect
30	Hover			140-150	14		Severe effect
31	Hover			190-200			No effect
32	*			60	2-5		*Quick stop & "push over" Severe effect

Wt. Begin - 2360 lbs.
Wt. End - 2270 lbs.
Prevailing Wind - 0 mph
O.A.T. - 44-46°F
H_I - 2780 ft.

Flight time - ∽ 40 min.

(1) Time vortex remained active after reaching the ground

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